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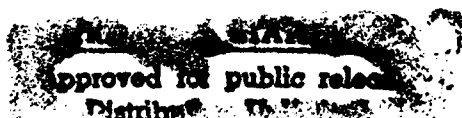


## **Establishment Criteria For LORAN-C Approach Procedures**

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<p>This report presents criteria for the establishment and discontinuance of LORAN-C nonprecision approaches. In compliance with P.L. 100-223, which requires that establishment criteria for airport traffic control towers and other navigational aids be promulgated via rulemaking, these criteria have been issued as Federal regulations and published at 14 CFR Part 170, Subpart C--LORAN-C. They effective September 10, 1993.</p> <p>The criteria for LORAN-C approaches require that, to be eligible for establishment, a candidate runway must meet all FAA standards for nonprecision approaches and must have life-cycle benefits that exceed life-cycle costs. Benefits of LORAN-C approaches are in the form of improved efficiency associated with lower approach minima. Lower minima permit runways to remain open at times when weather conditions would otherwise have closed an airport, thereby reducing flight disruptions. Site-specific activity forecasts are used with explicit dollar values assigned to passenger time and aircraft operating costs to provide a basis for comparing benefits to costs.</p> <p>Application of these criteria enable the Federal Aviation Administration to prioritize investments among alternative airports in a way that will maximize the benefits produced for the resources used.</p>				
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## I. INTRODUCTION

Although the establishment of a LORAN-C approach involves no ground based facilities and equipment expenditures, establishment and maintenance of such an approach still requires a commitment of resources from the Federal Aviation Administration (FAA) over an extended period of time. Good management practice requires that these costs be carefully considered together with the benefits to aviation system users in the decision to establish or discontinue a LORAN-C nonprecision approach. This report presents an economic analysis of LORAN-C nonprecision approaches, and develops and applies procedures for estimating LORAN-C benefits and costs. In essence, these procedures translate the value of services that LORAN-C will provide to users at an airport into a dollar measure--benefits--and compare that value to the cost of providing the services. The approach is analogous to investment analysis for FAA facilities and equipment programs contained in FAA Order 7031.2C, Airway Planning Standard Number One--Terminal Air Navigation Facilities and Air Traffic Control Services. (Reference 1)

### A. Description of a LORAN-C Approach

A LORAN-C nonprecision approach is established under United States Standard for Terminal Instrument Procedures (TERPS) which provides guidance for preparation, approval, and promulgation of terminal instrument approach procedures. (Reference 3) LORAN-C operates through a low-frequency transmission of timed signals, with controlled coded pulses that furnish nonprecision guidance to pilots with properly equipped aircraft. The LORAN-C signal is transmitted by groups of three to six stations called chains with each chain including a designated master station and several secondary stations.

A LORAN-C signal consists of pulses transmitted from a master station followed, after a controlled delay, by pulses from a secondary station in the chain. Time differences between the pulses correspond to the distance between receiver and transmitter. LORAN-C avionics use this information to derive the aircraft's location. Geographic location is determined by forming a line of position (LOP) that is determined by a set of points where time differences between the master and secondary station equal that being received by the aircraft. A similar LOP is computed relative to the master station and another secondary station. The point where the two LOPs cross determines the aircraft's exact location. (Reference 7)

### B. Types of Benefits and Costs

Economic criteria for a LORAN-C approach are based on one type of benefit and two types of costs:

- o Efficiency benefits derive from the ability of a LORAN-C nonprecision approach to lower the minimum approach level for a runway. A lower approach minimum means that the runway will remain open at times when weather conditions would otherwise have closed the airport, thereby reducing flight disruptions.
- o Investment costs include the initial costs associated with the development, publication, and flight testing of a LORAN-C approach procedure. Discontinuance of an approach has no significant costs.

- o Maintenance costs consist of annual flight inspections and annual updating of procedures.

### C. Economic Values and Activity Forecasts

Explicit dollar values which are assigned to passenger time and aircraft operating costs provide a basis for comparing benefits to costs. These values are reported in "Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Programs" (Reference 4). Values for the LORAN-C analysis are expressed in 1989 dollars, the last year for which all required data are available.

LORAN-C economic benefits are based on aviation activity projected in FAA's annual Terminal Area Forecast (TAF). (Reference 5) The TAF contains a 15-year, airport specific forecast of aviation activity by class of aircraft. The TAF activity forecast is a primary input to the FAA's Aviation Data Analysis System (ADA) that computes airport specific LORAN-C benefits and benefit-cost ratios.

Benefits and costs are based on a 15-year life cycle and are discounted to their present value using a 10 percent discount rate as directed by the Office of Management and Budget. (Reference 6) The 15-year life cycle is the same as that used for most facilities and equipment criteria.

### D. How the Criteria are Applied

FAA regional offices use the benefit-cost criteria, detailed in Chapter II, to determine the eligibility of a runway for a LORAN-C approach. A runway is eligible for establishment of a LORAN-C approach when the ratio of the approach life-cycle benefits to life-cycle costs is equal to or exceeds 1.0 and the runway meets all other requirements of the criteria.

An approach may be discontinued when the ratio of benefits to recurring maintenance costs expected over the remainder of its life-cycle is less than 1.

Meeting the economic criteria is a necessary condition to include a site in the FAA budget. However, meeting the criteria does not constitute a guarantee that the site will be funded.

### E. Organization of The Remainder of this Report

Benefit-cost criteria for a LORAN-C approach are summarized in Chapter II. Chapter III outlines costs and Chapter IV describes benefits of LORAN-C establishment. Chapter V reports results from the application of these criteria and the sensitivity of these results to key assumptions. Detailed information on unit costs of flight disruptions, economic values, and equipage rate.



## II. SUMMARY OF ESTABLISHMENT AND DISCONTINUANCE CRITERIA

### A. Introduction

This chapter summarizes establishment and discontinuance criteria for LORAN-C nonprecision approach procedures. The criteria will be promulgated via rulemaking and summarized in FAA Order 7031.2C, Airway Planning Standard Number One, Terminal Air Navigation Facilities and Air Traffic Control Services (APS-1). (Reference 1)

Satisfying the criteria neither insures nor constitutes an FAA commitment to establish or discontinue a LORAN-C approach. The criteria are but one of several inputs to the FAA decision process in the establishment of a LORAN-C approach. The criteria do not affect the responsibilities of the operating services to consider all other factors pertinent to the establishment or discontinuance decision.

### B. LORAN-C Benefit/Cost Criteria

LORAN-C criteria are a combination of technical requirements and a site-specific comparison of the present value of the life-cycle benefits with the present value of the life-cycle costs of a LORAN-C approach. A life cycle of 15 years is assumed to be a standard economic life in benefit-cost analyses supporting most FAA facilities and equipment criteria. The benefit and cost estimates use a discount rate of 10 percent, as prescribed by the Office of Management and Budget (Reference 6), to compute life-cycle costs and benefits. The ratio of life-cycle benefits to life-cycle costs provides a basis for qualifying a runway as a candidate for a LORAN-C approach. The ratio of remaining life-cycle benefits to the remaining life-cycle costs is the basis for LORAN-C discontinuance criteria. This analysis is facilitated by the Aviation Data Analysis (ADA) System which is maintained by the FAA Office of Aviation Policy and Plans.

#### 1. Establishment Criteria

a. A runway candidate must have landing surfaces judged adequate by the FAA to accommodate aircraft expected to use the approach and meet standard design criteria for nonprecision approach runways in accordance with Advisory Circular 150/5300.4B. (Reference 12)

b. A runway must be found acceptable for IFR operations as a result of an airport airspace analysis conducted pursuant to FAA Handbook 7400.2, Procedures for Handling Airport Matters, and meet all other requirements under United States Standards for Terminal Instrument Procedures (TERPS) and FAA Order 8260.19, Flight Procedures and Airspace. (Reference 3, 8, and 14).

c. The LORAN-C signal must be of sufficient quality and accuracy to pass flight inspection.

d. It must be possible to remove, mark, or light all approach obstacles in accordance with FAA Handbook 8260.3B (TERPS), FAA Advisory Circular AC70/7460.1 Obstruction Marking and Lighting, and CFR 14 Part 77. (Reference 3, 9, and 13).

e. Appropriate weather information must be available as indicated by United States Standards for Terminal Instrument Procedures (TERPS). (Reference 3)

f. Air-to-ground communications must be available at the initial approach fix minimum altitude and at the missed approach altitude as indicated by United States Standards for Terminal Instrument Procedures (TERPS). (Reference 3)

g. A runway meets the establishment criteria when it satisfies paragraphs B.1.a through B.1.f and the ratio of the present value of its life-cycle benefits (PVB) is greater than or equal to the present value of its life-cycle costs (PVC);

$$PVB/PVC \geq 1.0$$

## 2. Discontinuance Criteria

An existing LORAN-C approach satisfies the discontinuance criteria when the present value of its continued maintenance costs (PVCM) exceeds the present value of its remaining life-cycle benefits:<sup>1</sup>

$$PVB/PVCM < 1.0$$

---

<sup>1</sup> Because PVCM comprises 47 percent of PVC, this is equivalent to  $PVB/PVC < 0.47$ .

### III. COSTS

Establishment of a LORAN-C approach requires no ground based facilities or equipment expenditures. Nevertheless, FAA incurs costs in the establishment and maintenance of an approach. Establishment costs include expenditures associated with a runway end survey, compilation, interpretation and verification of runway survey data, an initial flight inspection, and approach chart development and publication. LORAN-C maintenance costs include the costs of an annual FAA flight inspection and an annual update of the approach procedures. Although LORAN-C discontinuance involves no significant costs, certain LORAN-C discontinuances may involve FAA costs which should be subtracted from the remaining life-cycle recurring costs when estimating the benefit-cost ratio for discontinuance.

Initial processing of a request for a LORAN-C approach takes place at the Regional Office. GS-14 level staff spend 40 hours collecting runway end survey data, conducting a feasibility study, preparing an environmental assessment, and coordinating the development of the approach procedure. (Reference 15) The runway survey data, costing about \$5,500 to develop, is either provided to FAA by the National Oceanographic Survey (NOS) or developed by the airport owner or sponsor. Next, Regional Office Air Traffic personnel produce required changes in the airports airspace plan which requires about 8 hours GS-14 level staff time.

Runway survey data and associated information developed in the Regional Office are sent to the Aviation Standards National Field Office (AVN) and Flight Inspection Field Office (FIFO). AVN verifies the survey data and enters the data into the Aircraft Management Information System (AMIS). The work performed at AVN requires about 8 hours of GS-12 level time. FIFO staff develop a standard instrument approach procedure (SIAP) for the runway requiring about 48 hours of GS-13 level time. A flight inspection of the SIAP is required involving an FAA aircraft and crew for 3 hours at a cost of \$2,800. The completed SIAP is then transmitted to the National Flight Data Center for data verification, inclusion in the Register, and publication by NOS and other charting agencies at a cost of about \$1,100.

Maintenance of a LORAN-C approach requires an annual flight inspection and an approach chart update. The annual flight inspection requires an aircraft and crew for 1 hour at a cost of \$940. The annual approach chart update costs approximately \$550.

Table III.1 summarizes LORAN-C development and maintenance costs. Non-recurring costs total \$13,200; discounted recurring costs equal \$11,900. Thus, the total discounted life-cycle costs of installing and maintaining a LORAN-C approach totals \$25,100. Note that the cost per hour for regional office and FIFO staffs is estimated using a fringe benefits factor of 28.15<sup>2</sup> and an adjustment factor for annual, sick, and other leave of 18 percent (Reference 2, p. 4-16.)

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<sup>2</sup> As a result of changes in the retirement system, OMB has been in the process of updating the fringe benefit factors for several years. The 28.15 percent factor used in this analysis was obtained by telephone from OMB staff. This factor includes the following elements.

Retirement	21.65 percent
Health	4.70
Other	1.80

Table III.1  
LORAN-C Nonprecision Approach Procedure Costs  
 (1989 \$)

	Hours	Cost per hour	Total cost
<u>Nonrecurring costs</u>			
Regional office data collection	40	\$40.04	\$ 1,602
Air Traffic airspace analysis	8	40.04	320
AVN data verification	8	28.49	228
FIFO approach development	48	33.88	1,626
Runway end survey			5,523
Initial flight inspection (3 hours)			2,811
Publication of approach chart			<u>1,105</u>
Sub total			\$13,215
<u>Recurring costs</u>			
	<u>Annual costs</u>	<u>Discount factor*</u>	<u>Total costs</u>
Annual flight inspection (1 hour)	\$552	7.977	\$ 4,405
Annual NOS update of charts	937	7.977	<u>7,475</u>
Sub total			<u>\$11,881</u>
Grand Total			\$25,095

\* Discount factor used for recurring costs is derived by the following formula:

$$\text{Discount factor} = \sum_{i=1}^{15} 1/(1+0.1)^{i-0.5}$$

Sources: Office of Flight Standards: AFS-230  
 Office of Budget: ABU-310

#### IV. LORAN-C NONPRECISION APPROACH BENEFITS

LORAN-C approach procedures provide nonprecision approach guidance to pilots with aircraft equipped with LORAN-C avionics. A major advantage of the LORAN-C approach procedures is that they allow the establishment of a nonprecision approach without facilities and equipment investment. The result is fewer flight disruptions by permitting approach minima to be lowered while maintaining a high level of safety, thereby allowing the runway to remain open in weather conditions in which it would otherwise have been closed.

Benefits are the cost savings associated with avoided flight disruptions. They are computed for each airport over a 15-year time frame based on operation forecasts from FAA's Terminal Area Forecast (TAF) (Reference 5) and other airport specific data. A safety benefit for LORAN-C was not included in the benefit-cost analysis. LORAN-C provides a nonprecision approach signal that guides a pilot to a specific heading that is in line with a runway. Upon descending to a specified altitude, it is then necessary for a pilot to visually complete the approach and landing. The level of safety is considered the same as during visual flight rules conditions.<sup>3</sup>

##### A. Landings

The net economic gain due to establishment, or loss due to discontinuance, of LORAN-C procedures depends on the change in the number of landings which result from the change in the runway approach minimum. For LORAN-C establishment, an increase in landings is the basis for determining reduced flight disruptions and economic benefits to runway users.

Equation (1) defines actual landings (LAND) by LORAN-C equipped aircraft before LORAN-C procedure establishment. The equation for actual landings is composed of two parts: (1) actual landings under VFR conditions, and (2) actual landings under IFR conditions. Note that actual landings will equal desired landings only if the PC factor in the following equation, equals zero.

$$(1) \text{ LAND}_0 = [(1 - \text{PIFR})/(1 - \text{PC}_0)][\text{OPS}/2] \\ + [(\text{PIFR} - \text{PC}_0)/(1 - \text{PC}_0)][\text{OPS}/2] B] L$$

where L                -    LORAN-C equipage rate,  
     $\text{LAND}_0$            -    actual landings by LORAN-C equipped aircraft prior  
                              to establishment of a LORAN-C approach,  
     $\text{PC}_0$                -    percent of weather below the minimum before LORAN-C  
                              procedure,  
    PIFR               -    percent of IFR weather,  
    OPS                -    number of operations, and  
    B                  -    IFR behavioral coefficient

---

<sup>3</sup> In contrast, precision approach systems provide vertical guidance in addition to a specific heading and are considered to enhance the level of safety for most flights occurring during instrument weather operations and to also improve safety if used during visual conditions.

The behavioral coefficient, B, measures the propensity of pilots to fly in IFR conditions. It is estimated by regressing actual landings on the expected number of landings during IFR weather.

If LORAN-C approach procedures result in a lower approach minimum, adverse weather will close the runway for a smaller proportion of time and the proportion of desired landings will increase. Equation (2) presents the functional relationship between landings and operations at the new minimum,  $PC_1$ .

$$(2) \text{ LAND}_1 = [(1 - \text{PIFR})/(1 - \text{PC}_0)][\text{OPS}/2] \\ + [(\text{PIFR} - \text{PC}_1)/(1 - \text{PC}_0)][\text{OPS}/2] B] L$$

where

$\text{LAND}_1$  - actual landings by LORAN-C equipped aircraft after establishment of a LORAN-C approach, and  
 $\text{PC}_1$  - percent of weather below the minimum after LORAN-C establishment.

Equations (1) and (2) estimate the landings before and after LORAN-C establishment. The difference in these values, indicated by equation (3), is the additional (reduced) number of approaches that will result from the lower minimum associated with establishment (discontinuance) of a LORAN-C approach.

$$(3) \text{ dLAND} = \text{LAND}_0 - \text{LAND}_1.$$

#### B. Runway Utilization

The gain in the number of landings shown in equation (3) cannot be fully realized since winds permit use of the runway only for a portion of the additional time it is open. That is, the fraction of the additional time an airport is open due to the installation of a LORAN-C approach is reduced by the fraction of that time the approach cannot be used because of excessive crosswinds and tailwinds. Based on a study of wind directions and speed during IFR weather, National average runway utilization rates were developed and used to calculate benefits at particular airports. If a site specific runway utilization factor is available, it should be used.

The realized increase in dLAND ( $\text{dLAND}_r$ ), is estimated by equation (4).

$$(4) \text{ dLAND}_r = u(\text{dLAND})$$

where  $u$  = runway utilization factor.

#### C. Flight Disruptions

An increase in landings will result in a decrease in disrupted flights due to avoided diversions, cancellations, and overflights. The reduced number of delayed flights can be estimated as a fraction of the sum of the other three flight disruption types (equal to increased landings).

Table IV.2 reports the proportional distribution of total flight disruptions by type of disruption. (Reference 10)

TABLE IV.2  
Flight Disruptions by Type  
(percent)

	<u>Hub</u>	<u>Non-hub</u>
Commercial Service		
Delay	67	38
Diversion	3	7
Cancellation	30	41
Overflight	--	14
Non-commercial Service		
Delay	38	38
Diversion	7	7
Cancellation	55	55

Because the ratio of delayed landings to other flight disruptions is equal to the ratio of delayed landings to increased landings, delayed landings for commercial service (CS) (hub and non-hub) and non-commercial service (NS) may be estimated as indicated in equations (5a) through (5c):

$$\begin{aligned}
 (5a) \text{ CS hub Delays} &= (67/33) u(d(LAND)) \\
 (5b) \text{ CS non-hub Delays} &= (38/62) u(d(LAND)) \\
 (5c) \text{ NS all Delays} &= (38/62) u(d(LAND))
 \end{aligned}$$

Total flight disruptions are the sum of avoided delayed flights and the other types of flight disruptions comprising the increased landings, or:

$$\begin{aligned}
 (6a) \text{ CS hub Flight Disruptions} &= [1 + (67/33)] u(d(LAND)) \\
 (6b) \text{ CS non-hub Flight Disruptions} &= [1 + (38/62)] u(d(LAND)) \\
 (6c) \text{ NS all Flight Disruptions} &= [1 + (38/62)] u(d(LAND))
 \end{aligned}$$

#### D. Valuation

Valuation of flight disruptions requires that a dollar value be placed on passenger time savings, passenger handling costs, airline revenue, and aircraft operation costs resulting from flight disruptions. Standard values for these parameters are used to compute the value of flight disruptions for each airport. The product of this value and total flight disruptions is the annual benefit of a LORAN-C approach. A full development of the formulas for flight disruption valuation is found in Appendix A.

#### E. Total Life-Cycle Benefits

The total benefits of a LORAN-C approach are measured by the present value of the stream of benefits over the approaches useful life. This is computed, as shown in equation (7), assuming a useful life of 15 years and using the OMB required 10 percent discount rate. (Reference 6)

$$(7) \quad PVB = \sum_{j=1}^{15} BA(j)/(1.1)^{j-0.5}$$

where      PVB      -      present value of benefits  
            BA(j)   -      total benefits for year j.



## V. RESULTS AND SENSITIVITY

### A. Criteria Results

This chapter presents the results from the application of the LORAN-C criteria to 4,078 airports in the Terminal Area Forecast data file. These results represent the highest B/C ratio for any runway at an airport. Only one runway per airport is selected, although in some cases an airport may be eligible for more than one approach.

Two key assumptions in this analysis are: 1) that LORAN-C reduces the ceiling minimum to 400 feet and visibility minimum to 1 mile; and 2) that the noncommercial and nonscheduled commercial service equipage rates for LORAN-C avionics is 3 percent in 1988 and rises to 71 percent by the year 2001 (see Appendix B). The analysis also assumes a life cycle beginning in 1991.

Figure V.1 presents a distribution of the LORAN-C B/C ratios for all airports for which benefit-cost calculations are made. Of the 4,078 airports in the sample, 1,778 (44 percent of the airports) have at least one runway with a B/C ratio of 1.0 or greater. Of the 2,300 airports for which LORAN-C is not cost beneficial, 615 airports (27 percent of these airports) had a B/C ratio above .25.

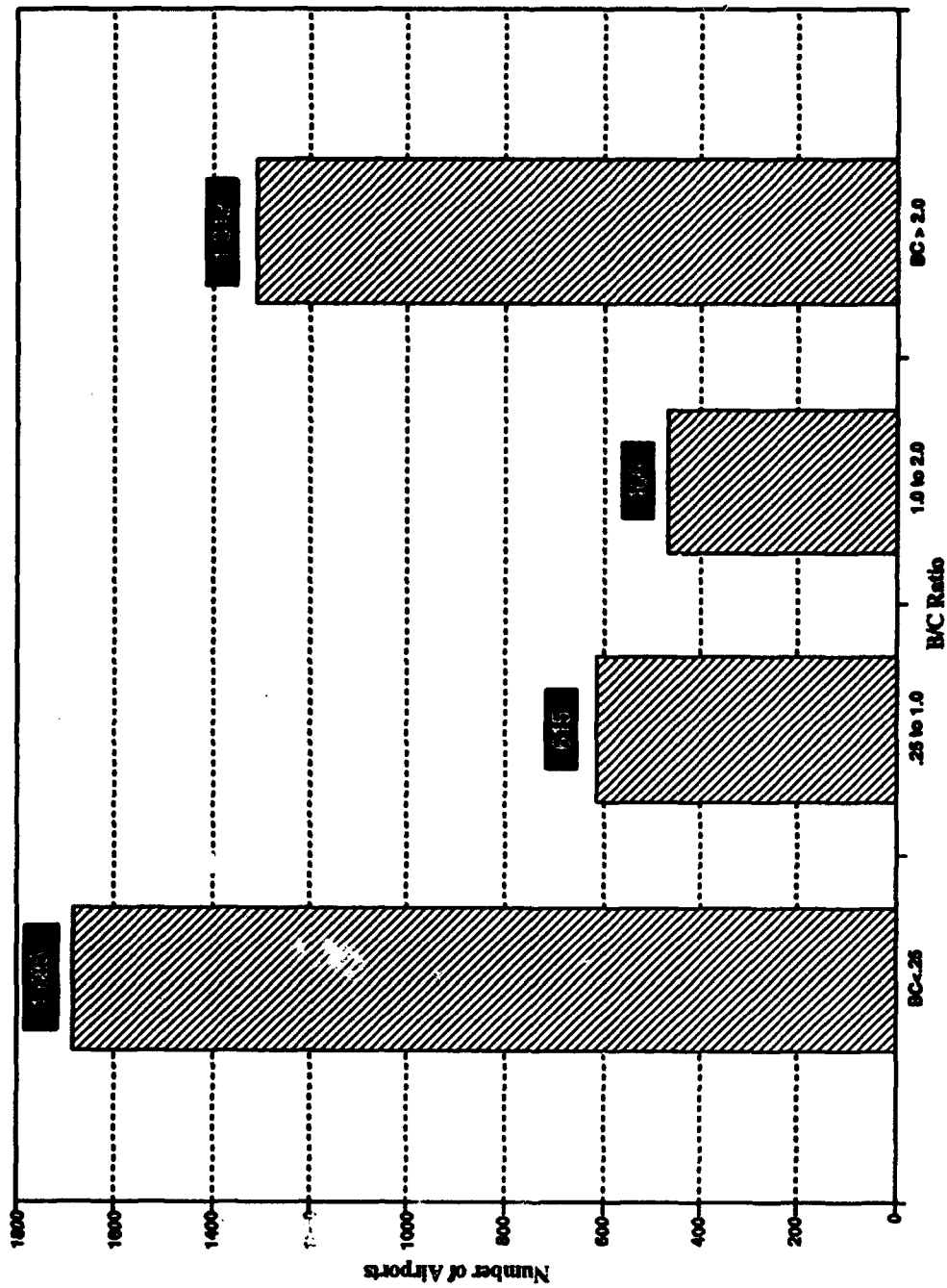
### B. Sensitivity Analysis

An important factor determining the number of qualifying runways is the cost estimate for establishing an approach. Also, the number of qualifying airports depends on the approach minimum that can be achieved with LORAN-C and the noncommercial and nonscheduled commercial service equipage rate. Sensitivity of the number of qualifying runways to a change in these key elements of the analysis is examined in Figures V.2 through V.4.

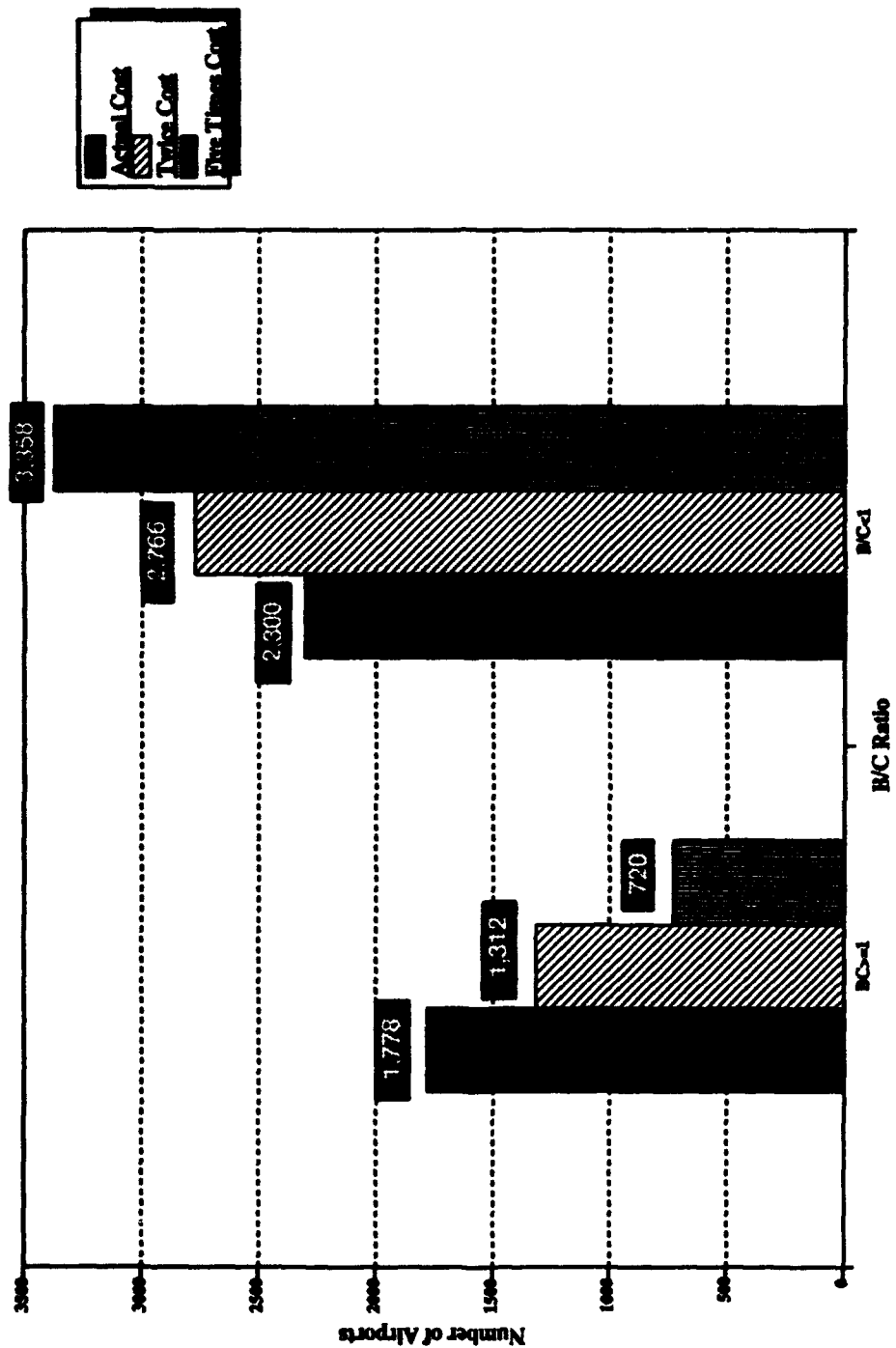
Figure V.2 reports the sensitivity of the results to the cost of developing and maintaining LORAN-C approach procedures. A doubling of the cost of LORAN-C results in a 26 percent decrease in the number of qualifying airports from 1,778 to 1,312. A five-fold increase in costs reduces the number of qualifying airports to 720.

Figure V.3 and V.4 report sensitivity analyses for the noncommercial service equipage rate and ceiling-visibility assumptions. Figure V.3 demonstrates that raising the initial noncommercial equipage rate from 12 percent to 24 percent in 1991 causes an 8 percent increase in the number of airports qualifying for a LORAN-C approach from 1,778 to 1,925 airports. Figure V.4 displays the effect of a change in the ceiling visibility assumption on the number of qualifying airports. If ceiling and visibility can only be brought down to only 500 and 1.5 miles instead of the assumed 400 feet and 1 mile, the number of qualifying airports would be reduced by 9 percent from 1,778 to 1,617 airports.

Figure V.1  
Number of Airports by B/C Ratio



**Figure V.2**  
**Cost Sensitivity Analysis**



**Figure V.3**  
**Equipment Rate Sensitivity**

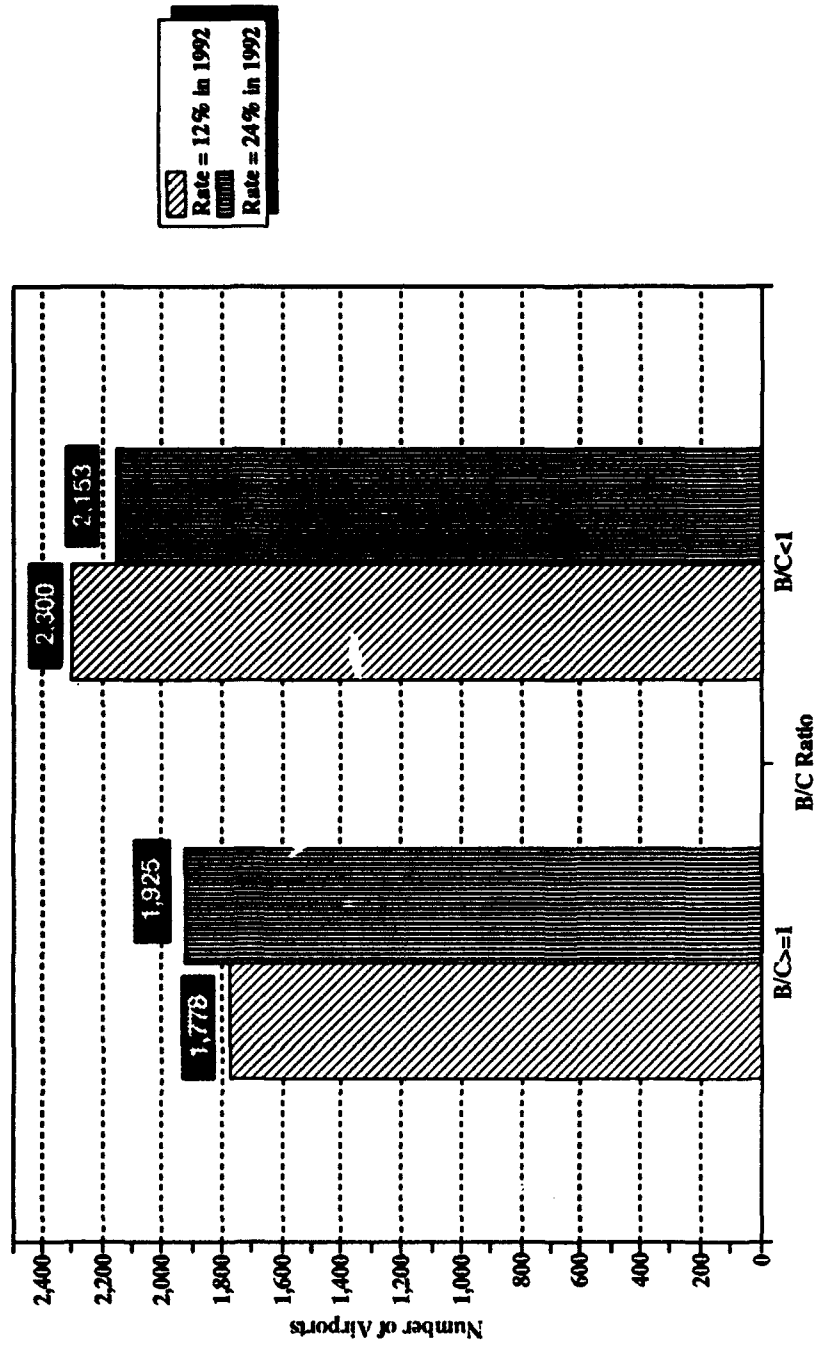
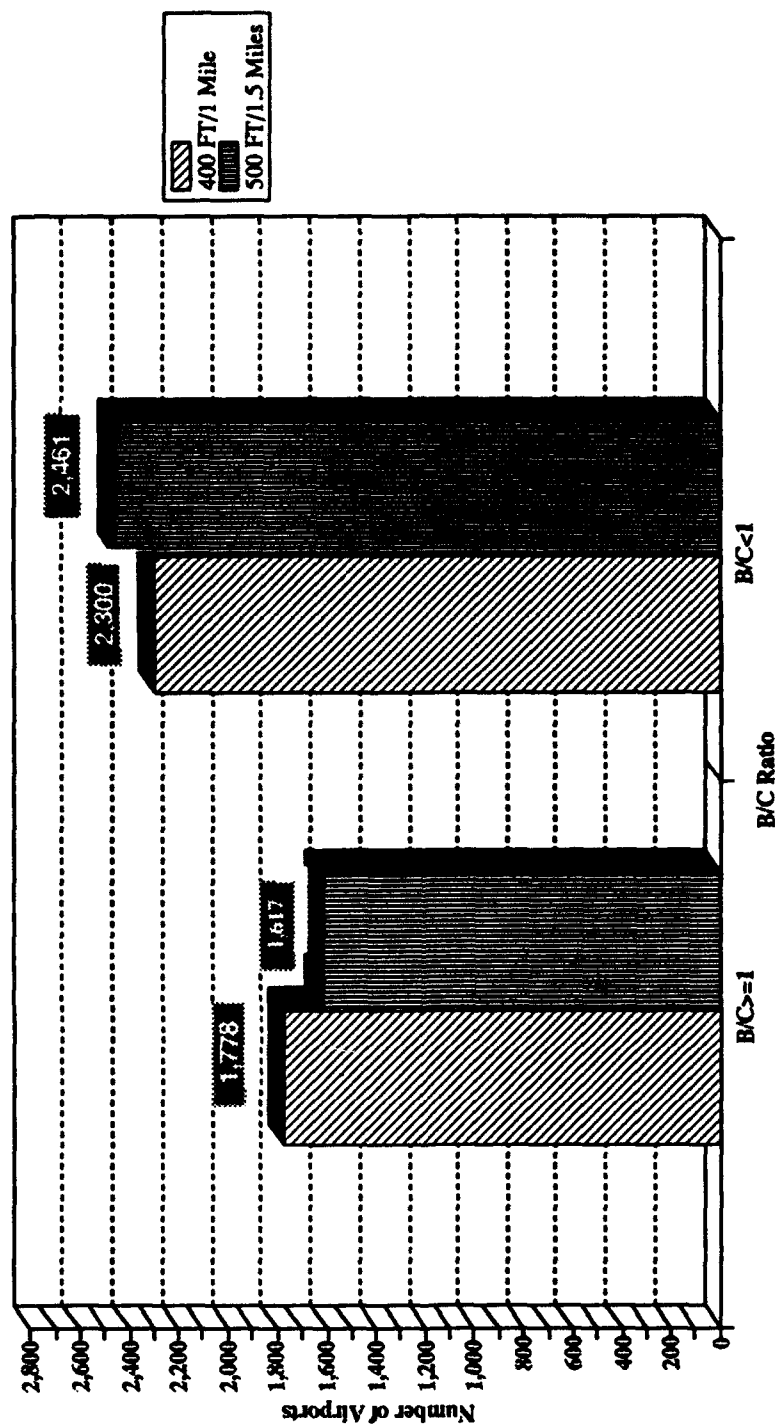


Figure V.4  
Ceiling and Visibility Sensitivity



### References

1. FAA Order 7031.2C, Airway Planning Standard Number One, Terminal Air Navigation Facilities and Air Traffic Control Services.
2. Economic Analysis of Investment and Regulatory Decisions - A Guide, Report Number FAA-APO-82-1, January 1982.
3. United States Standard for Terminal Instrument Procedures (TERPS), FAA Handbook 8260.3B.
4. Economic Values for Evaluation of Federal Aviation Administration Investments and Regulatory Programs, Report Number FAA-APO-89-10, October 1989.
5. Terminal Area Forecast, maintained by FAA's Office of Aviation Policy and Plans (FAA-APO-110).
6. Discount Rates to be Used in Evaluating Time-Distributed Costs and Benefits, Circular A-94 (Revised), Office of Management and Budget, March 27, 1972.
7. Flying with LORAN-C, Bill Givens, Tab Books Inc., Blue Ridge Summit, PA 17214, 1985.
8. Procedures for Handling Airport Matters, FAA Handbook 7400.2.
9. Obstruction Marking and Lighting, FAA Advisory Circular AC70/7460.1.
10. Establishment and Discontinuance Criteria For Precision Landing Systems, June 1983, FAA, Office of Aviation Policy and Plans, Report Number FAA-APO-82-10.
11. National Plan of Integrated Airports Systems, 1986-1995, Aviation Administration.
12. Utility Airports Air Access to National Transportation, Advisory Circular 150/5300.4B, 1975.
13. Code of Regulations 14, Parts 60 to 139, Revised as of January 1, 1988.
14. FAA Order 8260.19, Flight Procedures and Airspace.
15. Job and Task Analysis, Appendix D, FAA Office of Airworthiness, August 1985.

## AVERAGE UNIT COSTS OF INSTRUMENT FLIGHT DISRUPTIONS

### I. INTRODUCTION

Weather caused flight disruptions impose economic penalties on both aircraft operators and users. When the weather is forecasted to be below landing minima at the destination airport, the pilot can do one of four things depending upon the circumstances: (1) circle the airport until conditions improve (delay); (2) fly to a nearby airport where conditions are better (diversion); (3) continue to the next scheduled stop in the case of a multi-legged flight (overflight),; or (4) cancel the flight at the departure airport, if poor weather is forecast for an extended period (cancellation). This appendix develops average unit economic costs of instrument flight disruptions based on assumed operating scenarios of candidate locations for LORAN-C approach procedures. The outline of the analysis follows.<sup>1</sup>

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#### C. Non-commercial Service

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<sup>1</sup> No benefits are ascribed to military operations because the military is not expected to equip with LORAN-C.

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## II. AVERAGE UNIT INSTRUMENT APPROACH DISRUPTION COSTS

### A. Scheduled Commercial Service

#### 1. Scenario Development

Disruption of Scheduled Commercial Service (SCS) flights vary depending on the length of the flight and whether the destination is a hub or non-hub airport. In long-haul flights, airlines seldom cancel because the destination airport is forecast to be closed. If on arrival the destination airport is forecast to be open within approximately thirty minutes, the aircraft will usually hold. Otherwise, it will likely divert to another airport. Short- and medium-haul flights tend to take delays on the ground at the departure airport to conserve fuel and ease congestion at the destination airport. This saves equipment operating cost but not crew cost or the cost of passenger delay. If below-minima weather is forecast to persist at the destination airport, the flight may be canceled. Alternatively, if the airport is an intermediate stop along a route it may be overflown, creating a diversion for passengers intending to deplane and a cancellation for those expecting to board the aircraft.

Larger airports are served on average by larger aircraft than are smaller airports, making diversion or cancellation costs relatively higher. Consequently, flights destined to large airports are more likely to be delayed, than are flights destined to smaller airports. Because of these differences flight disruption cost estimating equations are developed separately for hub and non-hub airports.

#### 2. Scheduled Commercial Service

A sample of National Airspace Command Center (NASCOM) reported delays was examined for the six quarter period extending from January 1980 through June 1981.<sup>2</sup> The sample included days when below minima weather caused a significant number of delays of varying duration, as well as days when the number of weather-caused delays was comparably smaller. Analysis revealed that delays averaged 45 minutes at hub airports and 30 minutes at non-hub airports. For the purposes of the following analysis, it will be assumed that the 45 minute delay for hub airports consists of 15 minutes airborne delay and 30 minutes ground delay, based on FAA's Central Flow Control goal to limit airborne delay to an average of 15 minutes. For non-hub airports, the 30 minute delay will be apportioned between airborne delay of 10 minutes and ground delay of 20 minutes.

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<sup>2</sup> NASCOM compiles statistics only for flight delays exceeding 15 minutes. NASCOM data is considered appropriate for this analysis since weather-caused flight disruptions are typically longer than 15 minutes.



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### a. Costs Associated with Passengers

Passengers on a delayed flight are assumed to be delayed 45 minutes at hub airports and 30 minutes at non-hub airports. Passengers on a following flight may also be delayed because of the aircraft's late arrival. Equipment turnaround time, however, normally includes about 15 minutes of slack time. By foregoing scheduled slack time at subsequent, intermediate stops, delayed flights are able to make up some lost time. Nevertheless, boarding passengers would still have waited for the delayed flight and be delayed as much as passengers on the preceding legs, less the time made up by foregoing slack time.

An expression for passenger delay can be derived by examining what happens to each passenger on an aircraft when it is delayed and to each subsequent passenger. A sample of 624 flights from the Official Airline Guide (Reference A-2) was analyzed to estimate that, on average, an aircraft arriving at a destination has one additional destination to serve. Given a delay on the initial leg of "L" minutes, the "n" passengers on that leg experience an L-minute delay. On the remaining leg of the flight, the passengers experience a delay of L-15 minutes. The total approximate delay for hub airports is therefore  $n \times (2L-15)$ . Assuming L equals 45 minutes at hub airports, the total delay is 1.25 hours  $\times$  n passengers.

The situation is slightly different at non-hub airports, since it is assumed that half of the passengers are thru-passengers and are delayed only once. For a 30 minute delay on the leg to the non-hub destination, all of the passengers are assumed to be delayed thirty minutes ( $n \times 30$ ). The  $n/2$  boarding passengers on the next leg have a reduced delay due to a 15 minute foregone slack time and are delayed  $n/2 \times 15$  minutes. But the  $n/2$  thru-passengers who experienced the initial 30 minute delay have a 15 minute reduction in delay to foregone slack time, thus reducing their total delay to 15 minutes also. The total approximate delay for non-hub airports, therefore, is  $(n/2 \times 30) + (n/2 \times 15) + (n/2 \times 15) = 15n + 7.5n + 7.5n = 30n$  or .5 hours  $\times$  n passengers.

### b. Costs Associated with Aircraft Operation

When an aircraft is delayed on the ground, it incurs crew costs, and while airborne, full aircraft variable operating costs. Ground delay costs may be partially offset by foregoing scheduled slack time, so the 30 minute estimated ground delay is reduced to 15 minutes. From Reference A-3, crew costs on average represent approximately 26 percent of total aircraft variable operating costs of SCS operators. Using the term  $AOC_1$  for aircraft hourly variable operating costs at hub airports, the following expressions result:

Airborne delay	$0.25 \text{ hours} \times AOC_1$
Ground delay	$0.07 \text{ hours} \times AOC_1$
	-----
Total	$0.32 \text{ hours} \times AOC_1$

For non-hub airports, with an average 30 minute delay apportioned between airborne delay of 10 minutes and ground delay of 20 minutes less 15 minutes of foregone slack time, the following expressions result, with  $AOC_2$  representing air carrier aircraft hourly variable operating costs at non-hub airports:

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Airborne delay	0.17 hours x AOC <sub>2</sub>
Ground delay	0.02 hours x AOC <sub>2</sub>
Total	0.19 hours x AOC <sub>2</sub>

### c. Summary of Scheduled Commercial Service Delay Costs

Combining the costs associated with passengers and the costs associated with aircraft operation, the total costs per delayed aircraft SCS, where  $V_{PT}$  represents the hourly value of a passenger's time, are estimated to be:

At hub airports:  $(1.25 V_{PT}) n + 0.32 AOC_1$

At non-hub airports:  $(0.5 V_{PT}) n + 0.19 AOC_2$

### 3. Scheduled Commercial Service Cancellations

Unless extremely poor weather is forecast to remain for several hours, SCS operators generally do not cancel flights. But given a flight cancellation, the operator incurs passenger handling expenses, and passengers suffer delay. The carrier also loses revenue from the flight while avoiding aircraft variable operating costs.

#### a. Costs Associated with Aircraft Operation

There are two cancellation costs which are proportional to hours of aircraft operation--the cost avoided when the commercial service operator does not conduct the flight and the cost incurred when the aircraft must be repositioned for a future flight. An average of 1/2 hour extra flying time for repositioning is assumed. It is further estimated that 1/3 of canceled aircraft must be repositioned. Averaged for all cancellations, this yields 10 minutes extra flying time per cancellation (1/2 hour applied to 1/3 of the cancellations). The average duration of a hub airport flight in FY 1978, 1.25 hours (Reference A-4). The average flight duration of 0.58 hours (Reference A-4) is assumed for non-hub airports.

The following expressions of air carrier cancellation costs associated with aircraft operation result from the above analysis:

	<u>Hub Airports</u>	<u>Non-Hub Airports</u>
Repositioning aircraft (1/6 hour)	0.167 AOC <sub>1</sub>	0.167 AOC <sub>2</sub>
Less AOC savings	-1.25 AOC <sub>1</sub>	-0.58 AOC <sub>2</sub>
Total	-1.083 AOC <sub>1</sub>	-0.413 AOC <sub>2</sub>

These net negative costs represent the operating cost savings that result from a canceled flight.

#### b. Costs Associated with Passengers

There are two cancellation costs associated with passengers: lost revenue and passenger handling expenses, which are costs to the SCS operator, and delay, which is a cost to the passenger.

The prospective passenger must decide whether to schedule another flight, cancel his trip altogether, or seek an alternate mode of transportation.

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If the passenger elects to wait for the next available flight, the operator retains the passenger's ticket revenue with little added expense, since flights do not generally operate at full capacity. If the passenger does not continue by air, the revenue is lost by the SCS operator. Based on discussions with airline personnel, United Research (Reference A-5) developed estimates of the percentage of passengers who, after a cancellation, end up on another flight. The estimates range from 30 percent for short trips to 80 percent on longer trips. Airline personnel in a more recent survey could not update or verify these percentages. Because the reliability and speed of air transportation has improved, the upper end of the United Research range, 80 percent, is assumed in this study. This is expressible in terms of a per passenger cost to the operator as 20 percent of the average revenue per passenger, or 0.2 RPC.

It was determined through conversations with airline operations personnel that passengers waiting for flights that are later canceled can easily have already spent two hours at an airport waiting for the weather to improve. After the weather improves, passengers must wait for the next available flight which, according to the same sources, can easily add an additional three hours of delay. It is assumed, then, that a canceled flight results in an average total delay of five hours per passenger. This delay applies to the estimated 80 percent of those passengers who continue with their original plans to fly and also to the remaining passengers who divert to surface modes of transportation.

SCS cancellation costs associated with passengers on a per passenger basis are then:

Passenger handling expenses	$V_{CLC}$	0.2 RPC
Revenue loss		
"Lost" passenger time (5 hours)	$5 V_{PT}$	
Total	$5 V_{PT} + V_{CLC} + 0.2 \text{ RPC}$	

### c. Summary of Scheduled Commercial Service Cancellation Costs:

Combining the costs associated with aircraft operation and the costs associated with passengers, the total costs per SCS cancellation are estimated to be:

At hub airports:  $(5 V_{PT} + V_{CLC} + 0.2 \text{ RPC})n - 1.083 \text{ AOC}_1$   
At non-hub airports:  $(5 V_{PT} + V_{CLC} + 0.2 \text{ RPC})n - 0.413 \text{ AOC}_2$

It is additionally estimated that one half of the time cancellation of a flight results in cancellation of the following trip which the aircraft was scheduled to serve. Therefore, the above expressions are multiplied by 1.5:

At hub airports:  $1.5 ((5 V_{PT} + V_{CLC} + 0.2 \text{ RPC})n - 1.083 \text{ AOC}_1)$   
At non-hub airports:  $1.5 ((5 V_{PT} + V_{CLC} + 0.2 \text{ RPC})n - 0.413 \text{ AOC}_2)$

## 4. Scheduled Commercial Service Diversions

### a. Costs Associated with Aircraft Operation

Arriving aircraft may divert to another airport if below-minima weather is forecast for an extended period of time. Additional flying time in holding over

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the original destination airport and flying to an alternate destination is estimated to average one hour. After the weather improves, the aircraft usually must be ferried to another airport before it resumes scheduled operations, requiring an additional estimated half hour. The total additional flight time per diversion is therefore estimated to be 1-1/2 hours at an aircraft operation cost of 1.5 AOC<sub>1</sub> for hub airports and 1.5 AOC<sub>2</sub> for non-hub airports.

### b. Costs Associated with Passengers

Each passenger immediately "loses" one hour because of additional flight time. To this must be added the additional time required for the passenger to reach his desired destination. This may take the form of air or surface transportation and may involve the SCS operator providing passengers with meals and overnight lodging. If the return trip is by air, an extra hour of flight time is assumed plus two hours of waiting for the destination airport to accept arriving aircraft. Similar amounts of time are likely for surface transportation. Total time lost due to a flight disruption thus totals an estimated four hours per passenger. Airlines incur extra passenger-handling expenses for food, housing, and return-trip fare. The per passenger expense is thus:

Passenger handling expenses	$V_{DVC}$
"Lost" passenger time (4 hours)	$4 V_{PT}$
	-----
Total	$4 V_{PT} + V_{DVC}$

### c. Secondary Effects of Diversions

At non-hub airports there is a secondary effect of diversions, because the following trip on which the aircraft was scheduled to depart may be canceled. From airline data, it is estimated that this occurs on half of non-hub flights. Cancellation costs associated with passengers on a per passenger basis (developed above in Section II-A-3-b) are:

$$5 V_{PT} + V_{CLC} + 0.2 \text{ RPC}$$

The aircraft variable operating cost savings from avoiding the canceled leg are 0.58 AOC<sub>2</sub> (Section II-A-3-a). Combining these terms and multiplying by 0.5 to account for the estimate that half of the flights are affected, the secondary effect of an air carrier diversion at a non-hub airport is estimated to be:

$$0.5 ((5 V_{PT} + V_{CLC} + 0.2 \text{ RPC})n - 0.58 \text{ AOC}_2)$$

### d. Summary of Scheduled Commercial Service Diversion Costs

Combining the terms derived above, the costs associated with the diversion of an SCS aircraft are estimated to be:

$$\text{SCS at hub airports: } (4 V_{PT} + V_{DVC})n + 1.5 \text{ AOC}_1$$

At non-hub airports:

$$\begin{aligned} & (4 V_{PT} + V_{DVC})n + 1.5 (\text{AOC}_2) + 0.5 ((5 V_{PT} + V_{CLC} + 0.2 \text{ RPC})n - 0.58 \text{ AOC}_2) \\ & = (6.5 V_{PT} + V_{DVC} + 0.5 (V_{CLC} + 0.2 \text{ RPC}))n + 1.21 \text{ AOC}_2 \end{aligned}$$

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### 5. Scheduled Commercial Service Overflights

Overflights are assumed to apply at non-hub airports only. An overflight reduces aircraft variable operating costs, since when a stop is bypassed and the aircraft proceeds directly to its next destination, total flying time is reduced. These savings are offset in those instances when the pilot holds for a few minutes over the intended destination while deciding whether or not to attempt a landing.

An overflight results in a diversion for passengers intending to deplane and a cancellation for passengers intending to board the aircraft. The SCS incurs extra passenger handling expenses when stops are overflowed, just as it does with diversions and cancellations, and passengers, whether enplaning or deplaning, experience delays. For these reasons, an overflight is equated to a diversion plus a cancellation and, except for increased aircraft variable operating costs, costed accordingly. The per passenger cost of an SCS overflight is therefore estimated to be:

For a diverted passenger:			
Passenger handling expenses		$V_{DVC}$	
"Lost" passenger time (4 hours)	$4 V_{PT}$		
	-----		
Subtotal	$4 V_{PT} + V_{DVC}$		
For a canceled passenger:			
Passenger handling expenses		$V_{CLC}$	
"Lost" passenger time (5 hrs.)	$5 V_{PT}$		
Revenue loss			$0.2 \text{ RPC}$
	-----		
Subtotal	$5 V_{PT} +$	$V_{CLC} + 0.2 \text{ RPC}$	
	-----		
Total:	$(9 V_{PT} + V_{DVC} + V_{CLC} + 0.2 \text{ RPC}) n$		

### 6. Relative Distribution of Approach Disruptions

In this section the relative distribution of approach disruptions is derived so that the cost equations derived above can be weighted and combined into single and separate expressions for hub and non-hub airports.

Civil Aeronautics Board/FAA statistics (Reference A-6) and a methodology developed by United Research, Inc. (Reference A-5) are used to develop relative distribution estimates. An informal survey of five airlines was taken to test the current validity of the United Research results and appropriate changes were made.

The CAB/FAA statistics summarized below from Reference A-6 infer that 2.5 percent and 8.2 percent of certificated SCS departures in CY 1980 were canceled at hub and non-hub airports, respectively.

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Hub Size	Number of Hubs	CY 1980 Scheduled	CY 1980 Departures Scheduled and Completed*	
			<u>Number</u>	<u>Percent</u>
Hubs:				
Large	25	2,905,923	2,840,474	97.7
Medium	41	1,058,438	1,031,238	97.4
Small	<u>76</u>	<u>608,738</u>	<u>588,536</u>	96.7
Total	142	4,573,099	4,460,248	97.5**
Non-Hubs				
	486	606,383	557,165	91.9

\*Excludes extra sections      \*\*Weighted average

United Research found that about 2/3 of air carrier cancellations, on an annual basis, are due to weather. They also found that SCS diversions are about 1/6 as frequent as cancellations and that 5/6 of these diversions are caused by weather. The survey referenced above supports the United Research findings, except that the survey suggested the ratio of diversions to cancellations is closer to 1/10 than 1/6.

Weather-caused cancellations - 2.5% x 2/3  
- 1.7% of all flights

**Weather-caused diversions**

- 2.5% x 1/10 x 5/6
- 0.2% of all flights

An FAA-APO report, Airfield and Airspace Capacity/Delay Policy Analysis (Reference A-7), estimated that about 13.2 percent of all SCS arrivals were delayed 15 minutes or longer in 1980. Data collected by the FAA through its NASCOM program shows that of delays to IFR aircraft of over 30 minutes for the period 1971 through 1980, an average of 29 percent were due to weather. Applying the NASCOM percentage to the APO delay data suggests that 3.8 percent of all flights are delayed because of weather (13.2 percent x 29 percent).

**Recapitulating for hub airports:**

<u>Weather-Caused Flight Disruption</u>	<u>Hub Airports Percent of all Flights</u>	<u>Normalized Distribution %</u>
Delays	3.8	67
Cancellations	1.7	30
Diversions	0.2	3
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	5.7	100

Given that 8.2 percent of all air carrier flights into non-hub airports were canceled in 1980, estimates for the percentage of weather-caused cancellations and diversions can be derived following the method used above to estimate these rates for hub airports:

**Weather-Caused Cancellations**

- 8.2% x 2/3
- 5.5% of all flights

<b>Weather-Caused Diversions</b>	-	8.2% x 1/10 x 5/6
	-	0.7% of all flights

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An informal survey of several non-hub SCS operators revealed that 20 to 30 percent of cancellations result from overflights. Applying the median of 25 percent and applying it to the 5.5 percent for cancellations yields overflights as accounting for 1.4 percent of all flights, with 4.1 percent remaining as pure cancellations. The delay experience at non-hub airports is assumed to be similar to that at hub airports.

Summarizing for non-hub airports:

<u>Non-Hub Air Carrier Airports</u>		
<u>Weather-Caused</u>	<u>Percent of all Flights</u>	<u>Normalized</u>
<u>Flight Disruption</u>		<u>Distribution %</u>
Delays	3.8	38
Cancellations	4.1	41
Diversions	0.7	7
Overflights	1.4	4
	-----	-----
	10.0	100

### 7. Summary of Scheduled Commercial Service Approach Disruption Costs

Total estimated costs associated with weather-caused approach disruptions of SCS carrier flights can be determined by weighting the cost of each type of disruption by its relative frequency of occurrence and combining the respective results into one equation. For each equation, each term is multiplied below by its appropriate weight and a product obtained. Like variables are then summed and grouped into a single equation, representing the average unit cost of a SCS approach disruption. The individual equations, their respective weights, and the resulting average equations for hub and non-hub airports are summarized below:

#### Hub Airports:

<u>Disruption</u>	<u>Cost Equation</u>	<u>Weight</u>
Delays	$(1.25 V_{PT})n + 0.32 AOC_1$	0.67
Cancellations	$1.5 ((5 V_{PT} + V_{CLC} + 0.2 RPC)n - 1.083 AOC_1)$	0.30
Diversions	$(4 V_{PT} + V_{DVC})n + 1.5 (AOC_1)$	0.03
		-----
		1.00

The average unit cost of an air carrier approach disruption at a hub airport is thus estimated to be:

$$(3.21 V_{PT} + 0.03 V_{DVC} + 0.45 (V_{CLC} + 0.2 RPC))n - 0.24 AOC_1$$

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### Non-Hub Airports:

<u>Disruption</u>	<u>Cost Equation</u>	<u>Weight</u>
Delays $(0.5 V_{PT})n + 0.19 AOC_2$		0.38
Cancellations $1.5 ((5 V_{PT} + V_{CLC} + 0.2 RPC)n - 0.413 AOC_2)$		0.41
Diversions $(6.5 V_{PT} + V_{DVC} + 0.5 (V_{CLC} + 0.2 RPC))n + 1.21 AOC_2$		0.07
Overflights $(9 V_{PT} + V_{DVC} + V_{CLC} + 0.2 RPC)n$		0.14
		-----
		1.00

The average unit cost of an air carrier approach disruption at a non-hub airport is thus estimated to be:

$$(4.98 V_{PT} + 0.21 V_{DVC} + 0.79 (V_{CLC} + 0.2 RPC))n - 0.10 AOC_2$$

### B. Non-scheduled Commercial Service

#### 1. Scenario Development

Little data exists on the behavior of non-scheduled operators faced with weather-caused flight disruptions. NCS operators are assumed to operate in much the same manner as certificated route air carriers at non-hub airports described above in Section II-A.

#### 2. Non-scheduled Commercial Service Delays

##### a. Costs Associated with Aircraft Operation

NCS delay duration is assumed to be the same as non-hub air carriers, with an average 30 minute delay apportioned between airborne delay of 10 minutes and ground delay of 20 minutes. No foregone slack time, however, is assumed. From Reference A-3, crew costs on average represent approximately 39 percent of total aircraft variable operating costs. Aircraft variable operating costs for weather-caused air taxi delays are then:

Airborne delay	0.17 hours x $AOC_3$
Ground delay	0.13 hours x $AOC_3$
	-----
Total:	0.30 hours x $AOC_3$

where  $AOC_3$  represents NCS aircraft variable operating costs per airborne hour.

##### b. Costs Associated with Passengers

NCS passenger delay duration is assumed to be identical to that for SCS at non-hub airports -- 0.5 hours per passenger.

##### c. Summary of Non-scheduled Commercial Service Delay Costs

The total cost per delayed NCS aircraft is thus estimated to be:

$$(0.5 V_{PT})n + 0.30 AOC_3$$



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### 3. Non-scheduled Commercial Service Cancellations, Diversions and Overflights

Costs for NCS cancellations, diversions, and overflights are estimated to be the same as those for SCS at non-hub airports, except for the adjustments noted below. All values for lost passenger time are taken as half of those associated with SCS, because as a rule the number of passengers is smaller, the NCS organization is smaller, and final decisions regarding the handling of diverted or canceled passengers are made more quickly. Returning a passenger to his original destination is also less time consuming since stage lengths are shorter. For cancellations, another difference is the percentage of revenue recovery used in the flight cancellation scenario. United Research (Reference A-5) estimated that 70 percent of NCS passengers cancel their trips or use other means of travel when a flight is canceled. Finally, NCS operators are presumed not to reimburse passengers for expenses when a flight is canceled due to poor weather:

Cancellation:  $1.5 ((2.5 V_{PT} + 0.7 RPT)n - 0.413 AOC_3)$   
 Diversions:  $(3.25 V_{PT} + V_{DVT})n + 0.5 (.7 RPT)n + 1.21 AOC_3$   
 Overflights:  $(4.5 V_{PT} + V_{DVT} + 0.7 RPT)n$

where RPT is the average revenue per NCS passenger, and  $V_{DVT}$  is the passenger handling expense for diverted NCS passengers.

### 4. Summary of Non-scheduled Commercial Service Approach Disruption Costs

NCS approach disruption costs and the relative weight of each are summarized below:

<u>Disruption</u>	<u>Cost Equation</u>	<u>Weight</u>
Delays	$(.5 V_{PT})n + 0.30 AOC_3$	0.38
Cancellations	$1.5 ((2.5 V_{PT} + 0.7 RPT)n - 0.413 AOC_3)$	0.41
Diversions	$(3.25 V_{PT} + V_{DVT})n + 0.5 (.7 RPT)n + 1.21 AOC_3$	0.07
Overflights	$(4.5 V_{PT} + V_{DVT} + 0.7 RPT)n$	0.14
		----
		1.00

The average unit cost of a NCS approach disruption is thus estimated to be:

$$(2.57 V_{PT} + 0.21 V_{DVT} + 0.79 (.7 RPT))n - 0.06 AOC_3$$

## C. Non-Commercial Service

### 1. Scenario Development

Most non-commercial service (NS) flight disruption impacts due to weather are felt by business travelers flying in relatively large aircraft equipped for IFR operations. The pattern of flight disruptions experienced is probably similar to that estimated for NCS operators except that there are few secondary effects. The impact of flight disruptions on passengers is less because the aircraft in which they are traveling is generally available for use as soon as the weather clears. Because of the greater

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number of airports at which NS aircraft operate, diversion times are less. Interrupted trip expenses are incurred for meals and overnight accommodations in some cases.

Additional aircraft variable operating costs ( $AOC_4$ ) and interrupted trip expenses for canceled ( $V_{CL_2}$ ) and diverted ( $V_{DVG}$ ) passengers represent the major cost impacts resulting from approach disruptions of aircraft. No distinction is made between flight disruptions at hub and non-hub airports.

### 2. Non-commercial Service Delays

NS delay duration is assumed to be the same as that for NCS. Costs associated with aircraft operation are  $0.30 AOC_4$  and those with passengers are  $0.5 V_{PT}$ , for a total of:

$$(0.5 V_{PT}) n + 0.30 AOC_4$$

### 3. Non-commercial Service Cancellations

When a NS aircraft is forced to cancel a flight due to poor weather, no additional flying time, lost revenue, or passenger handling expense is involved. What remains from the NCS equation is merely  $2.5V_{PT} n$ .

### 4. Non-commercial Service Diversions

The cost of a general aviation diversion is again similar to NCS, but without the secondary effects. The equation is therefore:

$$(2.0 VPT + V_{DVG})n + 1.5 AOC_4$$

### 5. Summary of Non-commercial Service Approach Disruption Costs

NS flight disruption costs are weighted similar to those for SCS at non-hub airports and NCS, except the percentage for overflights is added to cancellations because overflights are presumed not to occur.

<u>Disruption</u>	<u>Cost Equation</u>	<u>Weight</u>
Delays	$(0.5 V_{PT})n + 0.30 AOC_4$	0.38
Cancellations	$2.5 V_{PT} n$	0.55
Diversions	$(2.0 V_{PT} + V_{DVG})n + 1.5 AOC_4$	0.07
		----
		1.00

The average unit cost of a general aviation approach disruption is thus estimated to be:

$$(1.71 V_{PT} + 0.07 V_{DVG})n + 0.22 AOC_4$$

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### D. SUMMARY

The following equations are reproduced from the preceding text:

Scheduled Commercial Service:

$$\text{Hubs: } (3.21 V_{PT} + 0.03 V_{DVC} + 0.45 (V_{CLC} + 0.2 \text{ RPC}))n - 0.24 \text{ AOC}_1$$

$$\text{Non-hubs: } (4.98 V_{PT} + 0.21 V_{DVC} + 0.79 (V_{CLC} + 0.2 \text{ RPC}))n - 0.10 \text{ AOC}_2$$

Non-scheduled Commercial Service:

$$(2.57 V_{PT} + 0.21 V_{DVT} + 0.79 (.7 \text{ RPT}))n - 0.06 \text{ AOC}_3$$

Non-Commercial Service:

$$(1.71 V_{PT} + 0.07 V_{DVC})n + 0.22 \text{ AOC}_4$$

### E. VALUE OF VARIABLES

Average weather-caused approach disruption costs are estimated in generalized form in this appendix to permit substitution of new values for the variables as their values change and are updated over time. Specific costs can be estimated by substituting the appropriate value for each variable and deriving the solution. The following values are denominated in 1988 dollars:

VPT	-	Hourly value of a passenger's time, \$35.00.
n	-	Number of passengers/occupants per flight leg is estimated on an airport specific basis. The national average for each service type follows: SCS-76.0 passengers at hub airports and 32.9 passengers at non-hub airports; NCS-2.3 passengers; NS itinerant - 3.1 occupants.
AOC <sub>1</sub>	-	SCS aircraft variable operating cost per airborne hour at hub airports. (National average is \$1,116)
AOC <sub>2</sub>	-	SCS aircraft variable operating cost per airborne hour at non-hub airports. (National average is \$616)
AOC <sub>3</sub>	-	NCS aircraft variable operating cost per airborne hour. (National average is \$218)
AOC <sub>4</sub>	-	NS aircraft variable operating cost per airborne hour. (National average is \$85)
V <sub>CLC</sub>	-	SCS passenger handling expense for canceled passengers, \$52; includes overnight lodging (Source: Reference A-8)
V <sub>DVC</sub>	-	SCS passenger handling expense for diverted passengers, \$76; includes overnight lodging, meals, and transportation to original destination (Sources: Reference A-8 and conversations with four airlines)
V <sub>DVT</sub>	-	NCS passenger handling expense for diverted passengers, \$64; includes overnight lodging and transportation to original destination (Sources: same as for V <sub>DVC</sub> above)

## Appendix A

- $V_{DVT}$  - NS passenger handling expense for diverted passengers, \$64;  
(same as for  $V_{DVT}$ )
- RPC - SCS average revenue per passenger, \$92; average domestic trip  
length of 750 miles applied to average ticket cost per  
passenger mile of 17 cents (Source: FAA-APO-110)
- RPT - NSC average revenue per passenger, \$21; average domestic trip  
length of 130 miles applied to average ticket cost per  
passenger mile of 16 cents (Source: FAA-APO-110)

## Appendix A

### References for Appendix A

- A-1 Sources: "Benefits of Reduced Flight Disruption," Appendix B to Report Number FAA-APO-82-10, Establishment and Discontinuance Criteria for Precision Landing Systems, September 1983, and Establishment Criteria for Category I Instrument Landing System (ILS), Report Number FAA-ASP-75-1, December 1975. Modified here for specific application to LORAN-C.
- A-2 Official Airline Guide, September 1981.
- A-3 Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Programs, Report Number FAA-APO-89-10, October 1989.
- A-4 Air Carrier Traffic Statistics, Civil Aeronautics Board, July 1979.
- A-5 Economic Criteria for Federal Aviation Agency Expenditures, Gary Fromm, United Research Inc., Cambridge, MA, June 1962.
- A-6 Airport Activity Statistics of Certificated Route Air Carriers, 12 Months Ended December 31, 1980, Prepared jointly by the FAA and CAB.
- A-7 Airfield and Airspace Capacity/Delay Policy Analysis, FAA Office of Aviation Policy and Plans, November 1981.
- A-8 Travel Market Yearbook, 1981.
- A-9 On Time Performance of Trunk Air Carriers, Form 438, Civil Aeronautics Board, Bureau of Accounts and Statistics, monthly.
- A-10 Aircraft Utilization and Propulsion Report, FAA, January 1976.

## APPENDIX B

### LORAN-C EQUIPAGE RATE

Benefits from establishment of a LORAN-C approach accrue only to aircraft equipped with LORAN-C avionics. Hence, estimation of benefits for any user group depends on the proportion of its fleet that is equipped. The following assumptions have been made with regard to the LORAN-C equipage rate.

Scheduled Commercial Service (SCS) operators are assumed to be 100 percent equipped with LORAN-C. SCS operators will equip because it is cost beneficial to do so. A disrupted flight at an average non-hub airport has an approximate cost of \$4,700. Thus, a good LORAN-C unit which generally costs less than \$25,000 would be paid for with about 6 fewer disrupted flights.

Noncommercial service operators are expected to equip more slowly than scheduled commercial service operators primarily because benefits due to the reduction in disrupted flights are relatively small. The Aircraft Electronics Association (AEA) estimates that at the beginning of 1988, 36,000 GA aircraft, or 17 percent of the GA fleet were equipped with LORAN-C units avionics. However, only 20 percent of all GA aircraft or 7,200 of the existing LORAN-C units are estimated to be IFR capable. All new LORAN-C units are expected to meet FAA Standards. Nonscheduled commercial service operators are assumed to have the same equipage rate as noncommercial service operators.

The number of LORAN-C avionics in noncommercial aircraft is expected to increase at a rate of about 9 percent of the total fleet per year until 1991 when the rate of growth should begin to decrease. The share of the fleet that will be LORAN-C equipped should rise to 70 percent by the year 2001. This share is approximately the proportion of the general aviation fleet which is IFR equipped. (See Figure B.1.)

The equipage rate for military is assumed to be zero, since Defense Department intends to use GPS as its primary navigation system.

Since each of the equipage rates is based on assumptions, the ADA program for calculating LORAN-C benefits will provide a means to change equipage rate.

Figure B.1  
Noncommercial Service Equipage Rate

